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(54) Title: BATTERY TESTING AND CLASSIFICATION
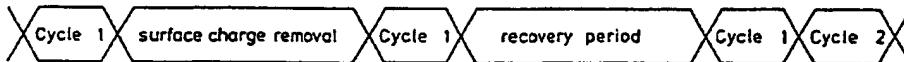
(57) Abstract

Method and apparatus for battery evaluation and classification applies transient microcharge and/or microload pulses to an automotive battery. Classification is made on the basis of analysis of the resultant voltage profile or portions or dimensions thereof. In one embodiment the analysis utilises a neural network or algorithm to assess a microcycle sequence of microload/microcharge tests utilising one of a series of battery parameters including impedance as well as voltage characteristics to effect classification. Another embodiment adopts an optimised (not maximum) level of prior test–based data–training for a self–organising neural network. A third embodiment utilises prior test data correlation to enalbe alorithm–based classification without use of a neural network.

BATTERY TESTING AND CLASSIFICATION

This invention relates to a method and apparatus for testing and classification of automotive and other batteries.

5   In the automotive industry and likewise in other technical areas, there is a need for improvements in systems for battery testing. We have provided an advance in the art in terms of the testing system disclosed in EP 0 762 135 A2 (case 12 reference P52759EP) which discloses
10   a method and apparatus for testing automotive electronic control units and batteries utilising neural networks to effect waveform analysis on a digitised signal. Battery testing is by waveform analysis of the battery current during transient connection of a load. A network learning
15   stage is employed together with a recognition test routine for characteristic waveforms. This approach is based upon software simulation of the waveform analysis which may be carried out visually by a person skilled in the art to distinguish between the current or voltage profiles of
20   various categories of batteries.

References identified in searches made with respect to the subject matter of the present application consist of the following:

25   US 4204153
            US 5469528
            US 5537327
            WO 96/35522
            WO 96/05508
30   GB 2285317A
            GB 2278452A

None of these is any more pertinent than WO 96/35522 which

discloses the use of a capacitor discharge pulse as a
battery test step to enable identification of battery type
by reference to voltage gradient using a voltmeter or
oscilloscope or digital signal processing device whereby
5   the battery type may be recognized prior to sorting
discarded batteries for recycling purposes.

FIRST ASPECT

In a first aspect of the present invention we are
10   seeking to provide a further technical advance in battery
test systems whereby the approach of simulating the visual
analysis carried out by a technical person is replaced by
an alternative approach in which the technical attributes
of computer systems are employed in a manner which
15   exploits their inherent advantages rather than by seeking
to constrain them to simulate a human analytical approach.

Accordingly, we have sought to utilise the capacity
of software systems to process and analyse data relating
to multiple parameters, in a way which the human brain
20   finds difficult. In accordance with this approach, we
realised that the multi-layer perceptron neural networks
of our above-identified EP '135 A2 specification had
limitations in terms of their requirement for the input
of an approximation to the required analytical answer in
25   any case.

In accordance with this new approach to battery
analysis, we sought to provide a system in which multiple
battery parameters, not all of them necessarily being
electric parameters, such as thermal parameters, would be
30   fed into the system and the system would be capable of
recognising particular characteristics of the complex data
fed in and thereby to effect an efficient classification
step, perhaps on the basis of relatively limited data as

compared with that required for waveform analysis.

An object of this aspect of the present invention
is to provide a method and apparatus for classification
of automotive and other batteries in accordance with one
5   or more sensed parameters thereof, offering improvements
in relation to one or more of the matters discussed above,
or generally.

According to the invention there is provided a
method of making battery test apparatus and there is also
10   provided apparatus for classification of automotive and
other batteries, as defined in the accompanying claims.

In an embodiment of the invention the system is
provided with a neural network in the form of a self-
organising network, namely a Kohonen network. In the
15   embodiment, this software network has undergone (or is
based upon software which has undergone) a controlled
degree of training. That training is based on a data
input comprising a representative sample of battery data.
Such a representative sample of battery data comprises a
20   plurality of battery parameters selected from the group
including voltage, current, internal resistance, surface
charge/capacitance, and thermal parameters. This
controlled degree of self-training provides a basis for
the classification step required from the self-organising
25   network.

In the embodiment also, the method and apparatus
provides test data generation means as part of the system
and which is adapted to subject a given battery on test
to test routines to generate test data for the
30   classification means. This test data is related to the
representative sample battery data on which the software
network was trained. For example, the software network
may be trained on data from a sequence of transient

battery loads or transient battery charging routines, these being separated likewise by relatively transient intervals. Where such a routine has been included in the training data, then the test data generation means
5   included in the battery test apparatus is arranged to generate corresponding data which leads to relatively efficient battery classification.

In connection with the use of multiple transient battery loads in the battery test routine, this approach
10 has practical significance in relation to the capacitance aspects of battery construction, namely that the sequence of multiple transient loads is capable of discharging the surface charge of the battery which is present due to the parallel plate construction of the latter and which can
15 otherwise provide misleading data arising from the (for example) 15 volts potential difference theron arising from alternator ripple.

The embodiments of the invention are software-intensive rather than hardware-intensive when compared
20 with previously known battery testing systems.

SECOND ASPECT

In accordance with a second aspect of the invention, there is a need in the automotive and other industries for
25 improved methods and apparatus for the testing and classification of batteries, notably the provision of systems which permit the in-situ testing of batteries using a minimum of hardware and making low power requirements while offering hand-held operational
30 characteristics and relatively rapid test/classification results, and an object of this aspect of the present invention is to provide a method and apparatus offering improvements in relation to one or more of these requirements, or indeed generally.

According to the invention there is provided a method and apparatus for the testing and/or classification of automotive and other batteries as defined in the accompanying claims.

In an embodiment of the invention described below there is provided a method and apparatus in which a battery is subjected to a microcycle test procedure and the result of that procedure is subjected to analysis by a neural network or by an adaptive algorithm, and by means of this new approach to the testing of automotive and other batteries, we have established that it is possible to test and classify batteries in accordance with their life and other criteria in a manner which yields advantages in accordance with several of the factors discussed above.

In the embodiment, the data analysis step is performed by means of an adaptive algorithm or by a neural network, and the battery test procedure includes the application of transient stimuli as part of a microcycle. The hardware provided for this purpose is minimised by this design approach and the test connection to the battery allows testing in-situ without violating automotive radio code systems nor electronic control unit software and the like.

The battery test routine, including the microcycle, provides for the application of a series of transient stimuli to the battery in the manner shown in the accompanying drawings, for example :-

    Voltage test;
    Microload;
    Surface charge removal;
    Microload;
    Recovery;

Microload;
Microcharge.

Within a microcycle of the above kind there may be
a series of positive or negative pulses applied to the
battery, such being implemented by a field effect
transistor (FET) gate.

By the use of a microcycle of transient
charges and/or loads applied to a battery in sequence in
accordance with this aspect of the invention there is
provided the advantage (with respect to our above-
mentioned EP '135A specification) that the practicality
and cost-effectiveness of the system, particularly for use
in a hand-held application, is unexpectedly advanced to
an extent such that a relatively sophisticated analysis
of a battery into the relevant one of a multiplicity of
categories by use of an easily-operated hand-held item of
equipment becomes a realistic option to an extent which
is no hitherto the case.

The number of pulses provided in a microcycle is
greater than one and generally anywhere in the range from
2 pulses to 100 or more. The voltages in the sequential
pulses may be increasing or decreasing or equal. The
number and frequency and voltage levels of the pulses may
be determined by an initial voltage test applied to the
battery, and/or ambient temperature and/or battery size,
and then the pulse characteristics may be determined by
data values obtained from subsequent pulses. In other
words, the algorithm determining pulse numbers, frequency
and levels is adaptive. Alternatively, prior knowledge
relating to the battery can be used, at least in part, to
set certain parameters of the pulse characteristics, these
depending on such data as battery history, known behaviour
etc.

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In the embodiments of the invention in which the method and apparatus provides for battery testing and/or classification by use of a microcycle comprising two or more transient charges and/or loads applied to a battery in sequence, the use of such a testing routine is, to the best of the Applicant's knowledge, novel in relation to test procedures for automotive and like or other battery systems. Conventional test procedures have hitherto involved procedures which may be termed microcycles which necessarily (and often by intention) involve the use of substantial charge flows and associated energy release, with corresponding associated technical shortcomings including provision of heat sink or similar means, and utility limitations restricting testing to non in-situ battery evaluation.

The described embodiments employ an analysis step or stage for battery data generated from the microcycle, and the embodiments employ a neural network or an adaptive algorithm to enable classification or numerical evaluation of a battery. The use of a neural network leads to the data processing advantages setforth in our prior application of 19 June 1997.

In the embodiments, Figs 11 and 12 of the drawings show battery responses to microload and microcharge cycles for both "good" and "bad" batteries.

Data employed in the analysis step of the invention is employed directly from the microcycle routine. Data may be in wave form format or in discreet datapoints format, and may represent relative or absolute values of the sampled battery characteristics. These latter may include impedance, bounce-back, peaks, areas, charge take-up, start and end voltages etc.

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THIRD ASPECT

In accordance with a third aspect of the present
invention there is provided a system in which the design
approach of the first and second aspects of the invention
5   is modified in order to achieve a substantial
simplification in terms of hardware/software provision and
analytical procedures, while still being based upon the
same analytical principle, and thus being able to provide
a comparable result in terms of battery classification
10   into the principal classes. In simple terms this aspect
of the invention provides a method and apparatus which is
capable of achieving an accurate battery classification
into, for example, the classes of bad/good but
discharged/good classes, but with the above-mentioned
15   structural and procedural simplification, with the
attendant corresponding cost advantages.

In accordance with this aspect of the invention, we
have discovered that in the method and apparatus of the
preceding aspect of the invention there can be achieved
20   the above-identified simplifications by the elimination
of the use of neural networks for analysis of the profiles
of the battery parameters for classification purposes.

This simplification and corresponding advance was
a relatively unexpected development in the course of our
25   research on this project, despite the background
experience which our earlier work involving the use of
neural networks provided. However, it was precisely the
knowledge of the results of test procedures involving
neural networks which provided the data whereby simplified
30   methods and apparatus could be adopted.

More specifically, knowledge of the results of test
procedures with neural networks enabled us to identify the
fact that a satisfactory correlation could be achieved

between battery classifications and test procedure
profiles using a relatively simple algorithmic procedure.
This procedure utilises previously-established data
relating to microcharge and/or microload voltage profiles
5   in order to define time intervals (from a defined time
such as the microload or microcharge commencement time)
at which to take characteristic sample voltages which
thereby become substantially as informative as analysis
of the entire profile itself.

10   Accordingly, according to this third aspect of the
present invention there is provided a method and apparatus
as defined in the identified ones of the accompanying
claims.

In the embodiment described below, the battery's
15   reaction to a transient test parameter applied to it
provides a measure of the condition of the battery. By
analysis of the waveform shape or profile (by reference
to the corresponding voltage at a characteristic point)
representative of the battery's reaction to the test
20   parameter, the corresponding classification step can be
effected.   This analysis step is effected in the
embodiment without employing a neural network by means of
an algorithm adapted to identify a corresponding one of
two or more battery condition classifications, and the
25   corresponding one of these classifications exhibits a
correlation with (voltage aspects of) the waveform profile
of the electrical value.

In the embodiment, voltage aspects of the waveform
profile utilised for this purpose include voltage values
30   giving a measure of impedance, voltage bounce-back,
voltage peaks, voltage troughs, voltage shape or profile,
charge take-up, and start and end voltages.

Also in the embodiment, the transient period of the

microload or microcharge applied to the battery lies in
the range of 1 to 1,000 milliseconds, and the repetition
interval between successive microloads and/or microcharges
varies from 2 to 100 times the duration of application of
5   the microload or microcharge.

In this aspect of the invention, the ability to
eliminate the neural network with its attendant cost
despite the retention of an analysis basis (relating to
test parameter profile) corresponding to that carried out
10   by the neural network, is of significant value and
benefit. The achievement of this step by a relatively
simple algorithmic hardware/based routine enables a
valuable product simplification to be achieved.

Embodiments relating directly to a second aspect of
15   the invention will now be described by way of example,
with reference to the accompanying drawings in which:
       Fig 1 shows a series of testing procedures forming
a complete test cycle;
       Fig 2 shows the profiles of voltage plotted against
20   time for a microload test sequence;
       Fig 3 shows the corresponding profile for a
microcharge test sequence;
       Fig 4 shows a microload circuit diagram for
transient load application to a battery on test;
25   Fig 5 shows the corresponding microcharge circuit
diagram;
       Fig 6 shows the microload circuit together with the
associated data acquisition and control systems;
       Fig 7 shows the corresponding microcharge circuit
30   corresponding to that of Fig 6;
       Fig 8 shows a block circuit diagram for a
comprehensive battery tester facility including microload
and microcharge functions, a corresponding microcontrol
system and a feed out to a display;
35   Fig 9 shows a plot for the results of a complete

battery test cycle showing the voltage/time profile with identification of the surface charge removal and recovery period steps;

Fig 10 shows a battery voltage/time plot for a typical response to a complete test cycle for an "average" battery;

Fig 11 shows a battery terminal voltage/time plot in a microload cycle with indication of the individual microloads applied by the FET and the corresponding voltage drops, both for a good battery and for a bad battery;

Fig 12 shows the corresponding plots for a microcharge cycle with corresponding plots for good and bad batteries;

Fig 13 shows a voltage/time plot for overshoot on recovery from a microloading step, which provides one of the classic analysable parameters for the purpose of the present invention; and

Figs 14, 15, 16A and 16B show simple algorithms in text and flow diagram format for use in the third aspect of the invention to identify the relevant one of three and four battery categories without use of a neural network.

FIRST ASPECT

The embodiment of the invention will now be described for the purposes of technical disclosure of the present invention, and reference is directed to our own prior-published specification EP 0 762 135 A2 and we hereby incorporate the entire disclosure of that prior specification into the present application. The present embodiment is based upon the disclosure in the above EP '135A2 specification with the below-indicated modification. Equally, the embodiment may be based upon the description below (in relation to the second aspect of the invention) which is based upon Figs 1 to 8 of the accompanying drawings, and likewise utilising the below-

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described Kohonen network.

The embodiment of this aspect of the present
invention uses a Kohonen Self-Organising Map in place of
the Multi-Layer Perceptron network disclosed in our prior
5   specification.

In place of the waveform analysis performed in our
prior technique, the embodiment utilises readings during
transient battery charge or discharge at certain
predetermined time intervals. In test routines, in place
10   of the 50 to 500 and preferably 150 to 300 milliseconds
period for transient discharge (in EP'135 A2), the present
embodiment has used periods in the range of up to 50
milliseconds, and preferably 10 to 20 milliseconds in
order to avoid unacceptable heat dissipation. The
15   apparatus includes test data generation means to subject
a battery to a test routine based upon such transient
loads or transient charge periods.

The Kohonen self-organising map is adapted to
uncover natural groupings within data presented to its
20   network and is capable of learning to respond to different
parts of the data input signal. The network consists of
neurons, which are initially given randomly assigned,
"weight" vectors in preparation for the training routine.
The neurons can be visualised as being arranged in a two-
25   dimensional grid. The weight vectors are provided in the
same format as the input signal. A neuron compares its
current weight vector with the input signal's content and
the number of matches made between these two vectors is
the output of the neuron.

30   The neuron that responds most strongly to an input
signal is identified and the neighbouring neurons around
this neuron are identified and the weightings of these
neurons are adjusted in order to give a stronger response

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to the relevant input signal. This weight adaptation
process is known as the training process. We have
discovered that over-training of the neurons leads to the
network giving a positive response only to signals
identical to those which it was trained on and this effect
is clearly undesirable.

A network can be trained on more than one signal at
once and a network can be trained to respond in other
areas of its grid to input signals that are significantly
different to a given one.

In the embodiments, data obtained during operation
of a conventional battery tester and resulting from
sampling at several predetermined intervals was, then
presented to a trained Kohonen self-organising network for
analysis. By reference to the established data patterns,
the network was able to classify the battery.

In the embodiment, the overall training data package
consisted of some 550 battery tests, each comprising
approximately 20 parameters. These parameters included
a three phase test procedure including firstly surface
charge removal, secondly charge test and thirdly heavy
load test, which was followed by a recovery period. Other
data provided to the network included Cold Cranking Amps
ratings (CCA), and calculated battery internal resistance.
This data block represented the basis for providing the
Kohonen network with its requisite modest training data
input requirements, for example a data sample of 60
battery tests chosen randomly from the above population
and each test comprising 20 data samples for each battery
state.

It is expected that it will be possible to cause the
system to be capable of distinguishing between different
modes of battery failure within the above-mentioned "bad-

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unserviceable" battery classification. Thus, for example, a battery may be regarded as worn out after a long length of service due to parasitic and gassing irreversible reactions, or the battery may have been damaged in some way. The differing electrical characteristics of such a battery may well be capable of classification by the Kohonen network.

In the embodiment, the classification output of the system provides a signal which is used for controlling a battery charging system responsive to the battery state. The classification signal is fed to a neural network controlling a battery charge rate system accordingly.

SECOND ASPECT

The second aspect of the invention provides a method and apparatus for battery testing and/or classification in which a microcycle of one or more transient charges and/or loads are applied to a battery in sequence and data relating to the battery reaction to the microcycle is analysed by a neural network or an adaptive algorithm to enable classification of the battery.

A further feature of the embodiment is that the analysis step is effected by the neural network or adaptive algorithm in relation to one or more of the following characteristics of the battery namely impedance, voltage bounce-back, voltage peaks, voltage troughs, voltage shape or profile, charge take-up and start and end voltages.

Fig 1 shows the sequence of transient test cycles (cycle 1, cycle 2) with intervening periods of battery surface charge removal and battery recovery.

In Figs 2 and Fig 3 the voltages applied to the field-effect transistors (FETs) in Figs 4 and 5 are shown.

As shown in the Fig 2 microload sequence, the time (T_2)
between successive microtests (V_1, V_2, V_3 etc) is greater
than (or equal to) the duration (T_1) of each test. Voltage
V_1 is less than V_2 is less than V_3. Overall test time (To)
5   is greater than or equal to 40 seconds.   For the
microcharge cycle, the voltage (V_4) on the field effect
transistor, is constant.

Figs 4 and 5 show the FETs in the microload and
microcharge   circuits   acting   as   switches   for   the
10   application of the transient loads and charges under the
control of a dynamic adjustment circuit seen in Fig 6.

In the circuits 10 and 12 of Figs 4 and 5 the
battery on the test is shown at 14 and the FETs at 16 and
15   18.   The microcharge voltage source is shown at 20.

Turning now to the system 22 shown in Fig 6, the
microload circuit 10 is constructed generally as shown in
Fig 4 with battery terminals 24,26 connected to the power
MOSFET   field   effect   transistor   switch   16   which   is
20   controlled by a dynamics adjustment circuit 28 which
responds to a microcontroller 30. Data acquisition system
32 serves to provide an interface for data acquisition and
transmission to the analysis function which forms part of
microcontroller 30 and is shown in more detail in Fig 8.

25   Generally, the power MOSFET applies a transient load
to battery terminals 24,26 for a selected period in the
range, for example of 20 to 100 microseconds.   The
reaction of the battery to this transient load and its
recovery, are examined and analysed. Typical results are
30   shown, for example, in Fig 11.

The power MOSFET typically has a maximum size of 30
millimetres by 20 millimetres and its average current
drawn is small and thus causes little damage to the

vehicle battery. The current drain represented by the
MOSFET can be altered by changing the gate voltage
controlled by microcontroller 30 through adjustment
circuit 28. The facility to vary the current drawn
5   provides the basis for determining the internal impedance
of the battery. In a similar way, other characteristics
of the battery are readily derivable from the voltage
profiles obtained in the method of the invention as
described in the embodiments, including various aspects
10   of voltage itself including voltage bounce-back, voltage
peaks and troughs, charge take-up and start and end
voltages. It is a feature of this aspect of the present
invention that classification may be effected by a profile
analysis in relation to one or more of these battery
15   characteristics. In several instances of these, a measure
of the magnitude of the relevant quantity is given by
examination of one portion or dimension of the profile of
the voltage trace produced during the test.

The use of transient microloads or microcharges in
20   this embodiment eliminates the requirement of certain
prior techniques for the use of large carbon piles,
whereby the test apparatus of the embodiment can be in the
format of a hand-held or otherwise mobile unit which can
be battery-powered or powered from a simple domestic
25   electricity supply.

An advantage of the microloading technique which we
have discovered is that it is effective to remove surface
charges from the battery, which otherwise adversely affect
the accuracy of testing.

30   Turning now to the microcharge circuit 34 of Fig 7,
this differs somewhat from the simplified system shown in
Fig 5. Battery terminals 24, 26 are coupled to a data
acquisition system 36 and a microcontroller 38. A pair
of power MOSFETs 40,42 act as switches to permit the

charging and discharging of a capacitor 44, which introduces a small packet of charge into the test battery via terminals 24, 26, very quickly, to provide transient battery-charging pulses.

5

The voltage source for the microcharges is identified (as in Fig 5) at 20 and may be provided by battery charge stealing or a boost from a docking station.

Fig 12 shows examples of battery response to the
10   microcharge cycle. The ease with which the battery accepts a charge pulse provides a measure of its condition, and likewise the battery's reaction after the pulse. Battery internal impedance and general battery condition are thus accessible by use of this technique.
15   The method can however be combined with the microcharging method as a more effective overall means of battery testing, and a combined system is shown in Fig 8.

In Fig 8, systems and components corresponding to those described above in relation to the preceding figures
20   are numbered accordingly and will not be re-described except as necessary. Additional systems and components shown in Fig 8 include signal-conditioning and multiplexing and analogue-to-digital circuits 46,48 and 50 respectively, of which multiplexer 48 is coupled to a
25   temperature thermistor 52.

A power supply unit 54 based on, for example rechargeable batteries, provides a compact source of power for the portable system 56 as a whole, of Fig 8.
The micro-controller identified at 30,38 (for
30   correlation with the micro-controllers of the previously-described circuits) incorporates a digital interface unit 58, a data storage function 60 and an algorithmic function 62 providing the stepwise analytical function for the electrical parameter inputs received by interface 58 at

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64,66,68 and 70.

A further connection 72 to interface 58 provides a user input and control function from a keyboard or other control input device 74. A display device 76 provides
5   direct indication of the recognised battery category, providing a direct indication of the relevant one selected on the basis of the waveform resulting from the analysis of the microcharge/microload sequence applied to the battery.

10   The analysis function is indicated at 62, being provided by an advanced or adaptive algorithm, or a neural network, in this embodiment.

By the use of a microcycle of transient charges and/or loads applied to a battery in sequence in
15   accordance with this aspect of the invention there is provided the advantage (with respect to our above-mentioned EP '135A specification) that the practicality and cost-effectiveness of the system, particularly for use in a hand-held application, is unexpectedly advanced to
20   an extent such that a relatively sophisticated analysis of a battery into the relevant one of a multiplicity of categories by use of an easily-operated hand-held item of equipment becomes a realistic option to an extent which has not hitherto been the case.

25   Data storage function 16 cooperates with the algorithmic/neural network function 52 in enabling a correlation of waveform and battery condition categories within the analysis sub-system 30,38. Implementation may be effected on a compatible PC system or custom hardware
30   providing the required digital signal processing functions, for example as available from Texas Instruments as noted in the EP '135 A2 specification mentioned above. Information mentioned on algorithms for the purpose is

available in the publication "neural networks in C++" by
Adam Blum, published by John Wiley & Sons. Simplified
algorithms as used in the third aspect of the invention
are shown in Figs 14, 15, 16a and 16b in text and flow
5   diagram format.

Fig 9 illustrates results obtainable with the system
of Fig 8 for a complete battery test cycle.

Fig 9 is a voltage/time plot illustrating a cycle
of three transient microloads 78,80,82 separated by two
10   recovery periods 84,86, followed by a transient
microcharge 88.

The voltage slope between the transient test steps
indicate changes including battery surface charge removal
at 84 between the first two microloads. The time interval
15   between the test steps is indicated on a linear scale by
the location of the relevant traces on that scale, the
microcharge step 88 following closely on the third
microload.

Fig 10 shows, in a voltage/time plot, the actual
20   results obtained for a battery in "average" condition.
The four microload/charge steps are indicated by the same
reference numerals as in Fig 9. The profiles are
characteristic of the battery classification, and taken
in combination with the actual values of the pre-and post-
25   test voltages detected provide a characteristic means for
identifying the specific classification which is
applicable.

Turning now to the graphic data shown in Figs 11 and
12, these show the voltage/time plots for not only the FET
30   gate or control voltages, but also the battery responses
for good and bad batteries. Fig 11 shows the microload
result and Fig 12 shows the microcharge result.

Fig 11 shows the effect of 5 microload cycles, these being accomplished within somewhat under 0.45 seconds (for all 5) with intermediate recovery periods of approximately three quarters of 0.1 seconds ie 0.075 seconds. Each individual load transient has a duration of approximately one quarter of 0.1 seconds ie 0.025 seconds.

The gate voltages for the tests show an increase from about 4 volts to about 6 volts from tests A to C and then remain constant. The corresponding five voltage drops for the plot 90 of a bad battery show characteristic significant drops at A and B with corresponding relatively steady-state profiles at C, D and E of which the amplitude and saw tooth profiles are characteristic.

In the plot 92 of a corresponding good battery the substantially reduced voltage dips and the correspondingly modified profiles of the dip and intermediate voltages provide the clear basis for a corresponding classification accordingly.

In Fig 12 which corresponds to Fig 11 but shows a sequence of three microcharge cycles or steps labelled F, G and H, the indications of the microcharge parameters in terms of the FET gate voltages and transient time intervals correspond very much to those of Fig 11 and therefore require no further comment.

The battery responses in Fig 12 for bad battery 90 and good battery 92 are readily distinguished in terms of the markedly enhanced resultant battery voltage step-up in the case of bad battery 90, as against the corresponding modest or almost negligible voltage shift for good battery 92.

Fig 13 shows, on a much shorter time scale, the voltage/time plot during the short recovery period

following a microload step.

It can be seen that the overshoot profile 94 has a well-defined saw-tooth rising profile on its leading edge 96. This is followed by a relatively uncharacterised and more steeply graded trailing edge 98 from peak 100, followed by an oscillating profile at 102 before the voltage settles down to the level 104 corresponding to the recovery from the microload level 106. It will be understood that such a profile provides a basis for clear battery classification separation caused by profile changes in the several identified areas resulting from battery state differences of the kind which are apparent from Figs 11 and 12.

THIRD ASPECT

This embodiment represents a simplification of the embodiment described above (second aspect) in which the neural network/advanced algorithm 62 of the data-analysing microcontroller 30,38 is replaced by a relatively simple algorithm which is adapted to identify a particular one of two or more battery conditions classifications exhibiting a correlation with the waveform profile resulting from the microcharge or microload steps discussed above in relation to the preceding embodiments. For this purpose, this embodiment examines voltage levels at characteristic (previously determined) points on the microload or microcharge voltage profile by reference to the time interval from commencement of the test.

Illustrative algorithms for the purpose of identifying the relevant one of three or four battery categories are set out in Figs 14, 15, 16A and 16B and represent relatively undeveloped stages in the algorithms' technical development in relating detected voltage parameters to battery condition categories.

Specifically, on the basis of the data storage
function 60 comprising the results of tests on batteries
in the relevant limited number of categories or
classifications applicable to this simplified apparatus,
5   we have found that a reliable level of acceptably accurate
classification can be achieved without the sophistication
and attendant cost inherent in the use of neural networks,
nor even is it necessary to employ the advance/adaptive
algorithms designated for the embodiment of Fig 8.
10 Operation of this simple embodiment proceeds generally in
accordance with matters described above, but with the
simplification represented by use of a reduced number of
battery categories such as simply "good / good discharged
/ bad."

CLAIMS

THIRD ASPECT

1.   A   method   for   determining   the
condition/classification of automotive and other batteries
in accordance with one or more sensed parameters thereof
comprising the steps of:
         a)   applying a transient electrical test parameter
to the terminals of a battery to be tested;
         b)   utilising a characteristic of the battery's
reaction to said test parameter as a basis for said
determination;
         c)   said method further comprising the step of
utilising the battery's reaction to said transient test
parameter to provide a measure of the condition of said
battery by analysis of the waveform shape or profile of
an electrical value representative of the battery's
reaction to said test parameter;
         characterised by
         d)   the step of analysis of the waveform profile
of said electrical value of the battery's reaction to said
test parameter being effected without employing a neural
network but by means of an algorithm adapted to identify
a corresponding one of two or more battery condition
classifications, and said corresponding one classification
exhibiting a correlation with time-defined voltage aspects
of said waveform profile of said electrical value.

2.   A   method   for   determining   the
condition/classification of automotive and other batteries
in accordance with one or more sensed parameters thereof,
comprising the steps of analysing the waveform shape or
profile of an electrical value of a battery's reaction to
a test parameter without employing a neural network and
by means of an algorithm adapted to identify a

corresponding one or two or more battery condition classifications, and said corresponding one classification exhibiting a correlation with voltage a0spects of the waveform profile of said electrical value, or a portion

5   or dimension thereof.

3.   A method according to claim 1 or claim 2 characterised by said electrical value representative of said battery's reaction to said transient test parameter comprising one or more of the following characteristics,

10   namely impedance, voltage bounce-back, voltage peaks, voltage troughs, voltage shape or profile, charge take-up, and start and end voltages.

4.   A method according to anyone of the preceding claims characterised by said analysis step being adapted

15   to relate the value of said electrical value to two or more ranges of such values which are representative of two or more corresponding condition classifications of such battery.

5.   A method according to anyone of the preceding

20   claims characterised by said transient test parameter being applied for one to one hundred milliseconds.

6.   A method according to anyone of the preceding claims characterised by said transient test parameter being repeated at intervals of from 2 to 100 times the

25   duration of said test parameter itself.

7.   Apparatus   for   determining   the condition/classification of automotive and other batteries in accordance with one or more sensed parameters thereof comprising:

30   a)   means for applying a transient electrical test parameter to the terminals of a battery to be tested;
         b)   analysis means adapted to utilise a

characteristic of the battery's reaction to said test
parameter as a basis for said determination;

      c)   said analysis means being adapted to utilise
the battery's reaction to said transient test parameter
to provide a measure of the condition of said battery by
analysis of the waveform shape or profile of an electrical
value representative of the battery's reaction to said
test parameter;

      characterised by;

      d)   said analysis means not comprising a neural
network and being adapted to effect said analysis by means
of an algorithm adapted to identify a corresponding one
of two or more battery condition classifications, of which
said one classification exhibits a correlation with time-
defined voltage aspects of the waveform profile of said
electrical value.

      8.   Apparatus   for   examining   the
condition/classification of an automotive or other battery
characterised by analysis means adapted to analyse the
waveform profile of an electrical profile of a battery's
reaction to a test parameter, said analysis means not
comprising a neural network and employing an algorithm to
identify a battery condition classification exhibiting a
correlation with voltage aspects of a waveform profile
detected.

      9.   Apparatus according to claim 7 or claim 8
characterised by said analysis means being adapted to
effect said analysis by reference to one or more of the
following battery characteristics namely impendence,
voltage bounce-back, voltage peaks, voltage troughs,
voltage shape or profile, charge take-up and start and end
voltages.

      10.   Apparatus according to anyone of claims 7 to
9 characterised by said analysis means being adapted to

relate the value of said electrical value to two or more ranges of said values which are representative of a corresponding two or more battery condition classifications.

5   11.   Apparatus according to anyone of claim 7 to 10 characterised by said apparatus being adapted to apply said transient test parameter for from 1 to 100 milliseconds.

      12.   Apparatus according to anyone of claims 7 to
10   11 characterised by said apparatus being adapted to repeat said transient test parameter at intervals from 2 to 100 times the duration of said test parameter.

FIRST ASPECT

      13.   A method of making battery test apparatus for
15   classification of automotive and other batteries in accordance with one or more sensed parameters thereof, the method comprising:
      a)   providing data input coupling means adapted to couple a battery to data classification means;
20   b)   providing said data classification means to be coupled by said coupling means to said battery so that said battery provides a data source permitting classification of said battery's state;
      c)   said classification means being provided
25   comprising a neural network and said neural network being adapted to carry out a classification step on said data accordingly;
      characterised by;
      d)   providing said neural network in the form of
30   a self-organising software network, such as a Kohonen self-organising network;
      e)   said method further comprising causing said

self-organising software network to undergo (or be based
upon software which has undergone) a controlled degree of
training thereof based on an input comprising a
representative sample of battery data, said representative
5   sample of battery data comprising a plurality of battery
parameters and selected from the group including voltage,
current, internal resistance, surface charge/capacitance
and thermal parameters; and

         f)   said method further comprising providing said
10   battery test apparatus with test data generation means
adapted to subject a given battery on test to test
routines to generate test data for said classification
means through said coupling means, which test data is
related to said representative sample of battery data on
15   which said software network was trained, whereby said test
data may be readily classified by said data classification
means.

         14.   A method of making battery test apparatus for
classification of automotive and other batteries and other
20   electrical systems in accordance with one or more sensed
parameters thereof, the method comprising classification
means comprising a self-organising neural network and
causing same to undergo (or be based upon software which
has undergone) a controlled degree of training thereof on
25   representative data, said representative data comprising
a plurality of battery parameters, and said method further
comprising providing test data generation means adapted
to generate related battery data from a battery on test.

         15.   A method according to claim 13 of claim 14
30   characterised by employing as said neural network a
Kohonen self-organising software network.

         16.   A method according to any one of claims 13 to
15 characterised by said representative sample of battery
data comprising data obtained from tests in which a

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transient load or a transient charge is applied to a battery.

17.   A method according to claim 16 characterised by one or more transient loads or transient charges being applied to said battery in sequence, said sequence comprising one or more loading or charging cycles at transient intervals, said loading or charging cycles and said intervals being up to 100 milliseconds in duration.

18.   A method according to any one of the preceding claims 13 to 17 characterised by employing said self-organising network to identify groupings of data within said data from said battery.

19.   A method according to any one of the preceding claims 13 to 18 characterised by causing said neural network to effect classification of said battery as good, or good discharged, or bad unserviceable.

20.   A method according to any one of the preceding claims 13 to 19 characterised by the further step of using said generated classification as a basis for controlling a battery charging system for said battery.

21.   A method according to claim 20 characterised by the step of controlling said battery charging system by means comprising a neural network.

22.   Apparatus for classification of automotive and other batteries in accordance with one of more sensed electrical parameters thereof, said apparatus comprising;
    a)   data input coupling means adapted to couple a battery to data classification means;
    b)   data classification means adapted to be coupled by said coupling means to a battery so that said battery provides a data source permitting classification

of said battery's state;

c) said classification means comprising a neural network adapted to carry out a classification step on said battery data accordingly.

5   characterised by;

d) said neural network comprising a self-organising software network, such as a Kohonen self-organising network;

e) said self-organising network having undergone

10   (or being based upon software which has undergone) a controlled degree of training based on data input comprising a representative sample of battery data, said representative sample of battery data comprising a plurality of battery parameters selected from the group

15   including voltage, current, internal resistance, surface charge/capacitance and thermal parameters, said data providing a basis for the classification step required from said self-organising network; and

f) said apparatus further comprising test data

20   generation means adapted to subject a given battery on test to test routines to generate test data for said classification means through said coupling means, which test data is related to said representative sample of battery data on which said software network was trained,

25   whereby said test data may be readily classified by said data classification means.

23. Apparatus for classification of automotive and other batteries and other electrical systems in accordance with one or more sensed parameters thereof, the apparatus

30   comprising classification means comprising a self-organising neural network adapted to effect a controlled degree of training thereof on the basis of sample battery data comprising a plurality of battery parameters or other data, and said apparatus further comprising test data

35   generation means to subject a test battery to routines generating data related to the training data for said

self-organising network.

24.   Apparatus according to claim 22 of claim 23
characterised by said neural network comprising a Kohonen
self-organising network.

5   25.   Apparatus according any one of claims 22 to 24
characterised by said representative data sample of
battery data comprising data obtained from tests in which
a transient load or a transient charge is applied to a
battery.

10   26.   Apparatus according to claim 25 characterised
by one or more transient loads or transient charges having
been applied in a sequence comprising one or more loading
or charging cycles at transient intervals, said loading
or charging cycles and intervals being up to 100
15   milliseconds in duration.

27.   Apparatus according to any one of claims 22 to
26 characterised by said self-organising network being
adapted to identify groupings of data within said data
20   from said battery.

28.   Apparatus according to any one of claims 22 to
27 characterised by said classifying means being adapted
to classify said battery as good, or good but discharged
25   or bad and unserviceable.

29.   Apparatus according to any one of claims 22 to
28 characterised by a battery charging system for said
battery and control means for said battery charging system
adapted to effect a degree of control in accordance with
30   the battery classification generated.

30.   Apparatus according to claim 29 characterised

by said control means of said battery charging system
comprising a neural network.

31.   A method for classification of automotive and
other batteries in accordance with one or more sensed
parameters thereof, the method comprising providing
apparatus according to claim 10 or 11 characterised by the
step of causing said test data generation means to subject
said battery to test routines generating test data for
said classification means through said coupling means,
which test data is related to said representative sample
of battery data on which said software network was
trained, and the method comprising causing said
classification means to classify said test data.

SECOND ASPECT

32.   A   method   for   determining   the
condition/classification of automotive and other batteries
in accordance with one or more sensed parameters thereof
comprising the steps of:

a)   applying a transient electrical test parameter
to the terminals of a battery to be tested;

b)   utilising a characteristic of the battery's
reaction to said test parameter as a basis for said
determination;

c)   said method further comprising the step of
utilising the battery's reaction to said transient test
parameter to provide a measure of the condition of said
battery by analysis of the waveform shape or profile of
an electrical value representative of the battery's
reaction to said test parameter;

characterised by

d)   applying at least one further transient
electrical test parameter to said battery to be tested;

e)   said one and said further transient electrical
test parameter forming a microcycle of two or more

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transient charges and/or loads applied to said battery in sequence;

    f)   analysing data relating to the battery's reaction to said microcycle by a neural network and/or an algorithm to enable classification of said battery.

    33.   A method according to claim 32 characterised by said analysis step being effected in relation to one or more of the following characteristics of the battery namely impedance, voltage bounce-back, voltage peaks, voltage troughs, voltage shape or profile, charge take-up, start and end voltages.

    34.   Apparatus for determining the condition/classification of automotive and other batteries in accordance with one or more sensed parameters thereof comprising:

    a)   means for applying a transient electrical test parameter to the terminals of a battery to be tested;

    b)   analysis means adapted to utilise a characteristic of the battery's reaction to said test parameter as a basis for said determination;

    c)   said analysis means further being adapted to utilise the battery's reaction to said transient test parameter to provide a measure of the condition of said battery by analysis of the waveform shape or profile of an electrical value representative of the battery's reaction to said test parameter;

    characterised by

    d)   means for applying at least one further transient electrical test parameter to said battery to be tested;

    e)   said one and said further transient electrical test parameters forming a microcycle of two or more transient charges and/or loads applied to said battery in

sequence; and

f)   said analysis means being also adapted to
analyse data relating to the battery's reaction to said
microcycle by a neural network and/or an algorithm to
enable classification of said battery.

35.   Apparatus according to claim 34 characterised
by said analysis means being adapted to effect said
analysis steps in relation to one   or more of the
following characteristics of the battery namely
impedeance, voltage bounce-back, voltage peaks, voltage
troughs, voltage shape or profile, charge take-up and
start and end voltages.

-1/14-
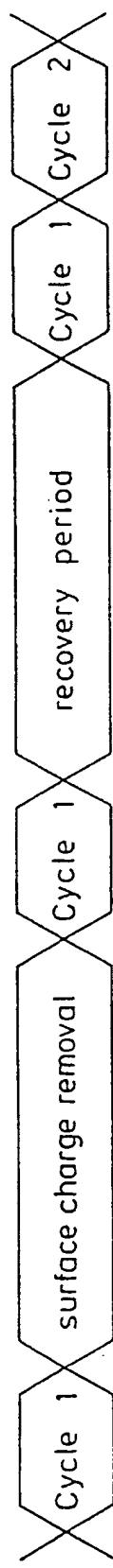
FIG. 1
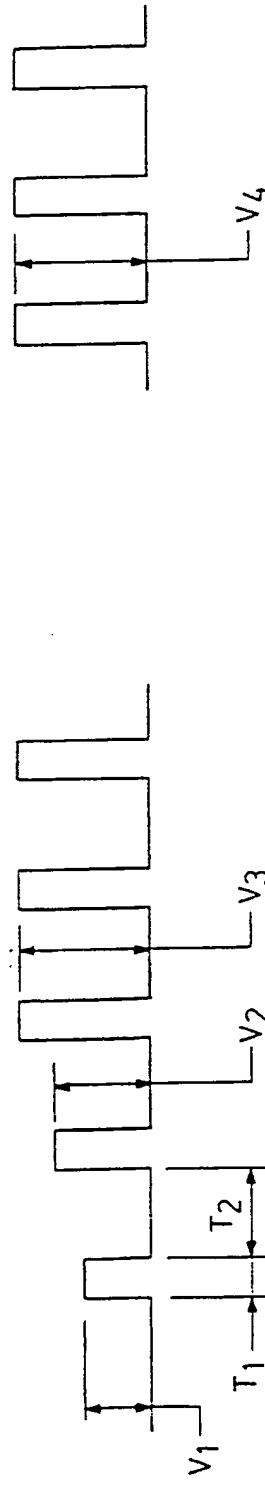
FIG. 2

FIG. 3
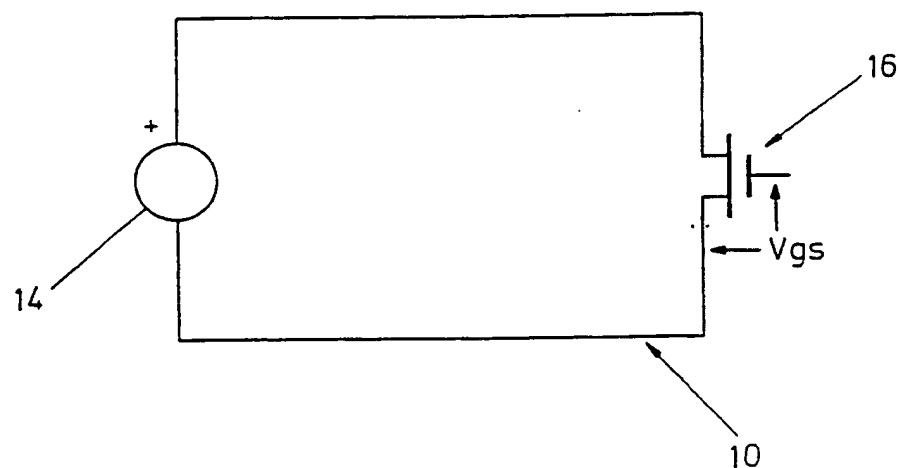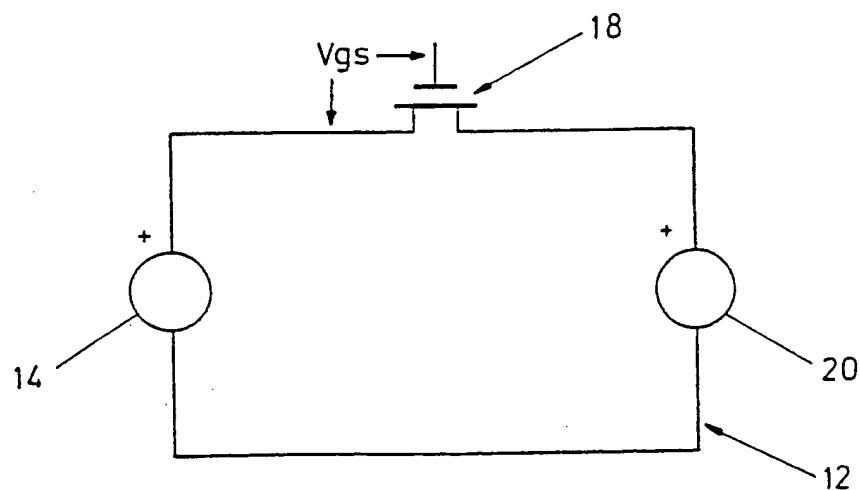
16

14

Vgs

10

FIG.   4

18

Vgs

14   20

12

FIG.   5

FIG. 6

FIG. 7

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FIG. 8
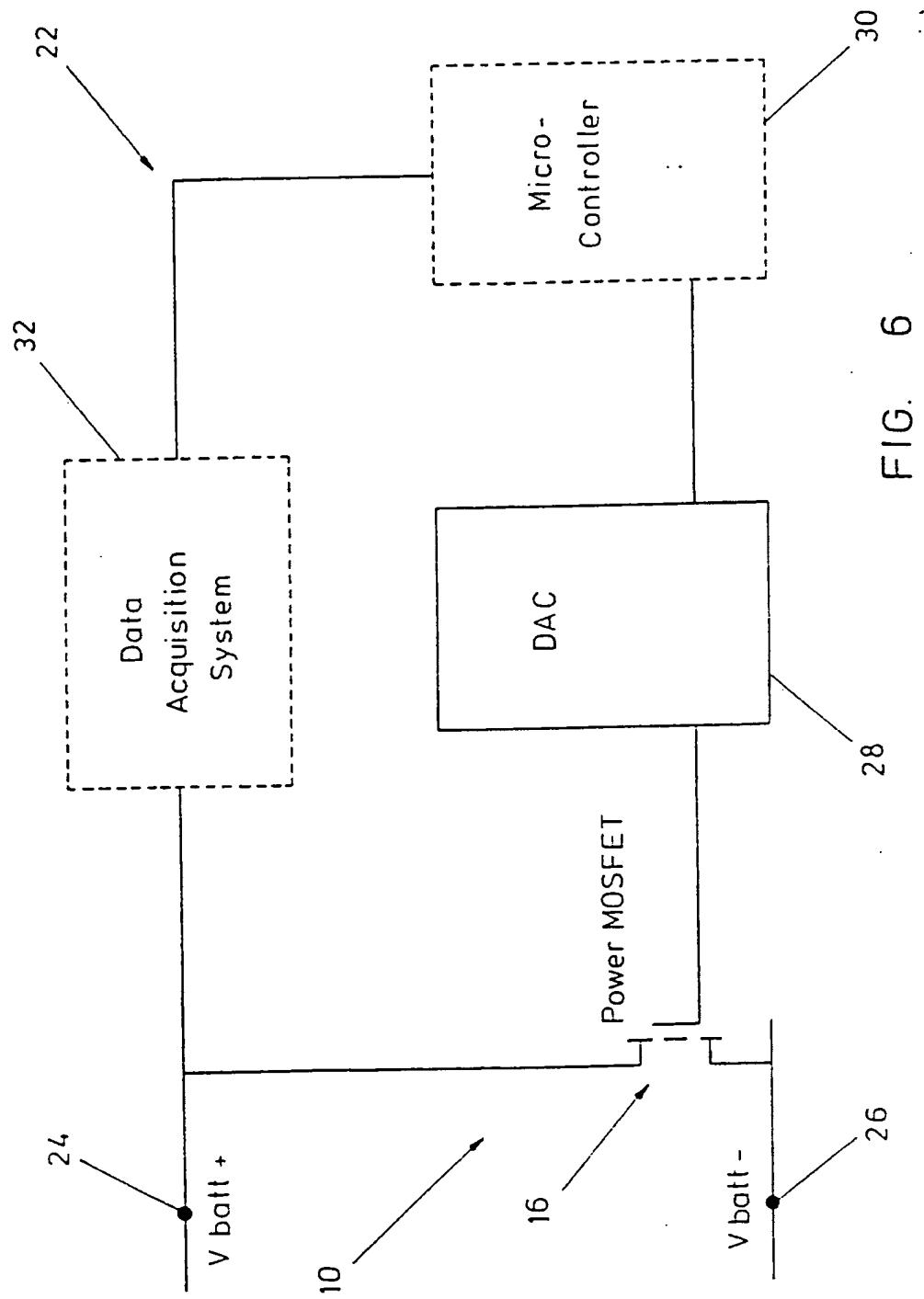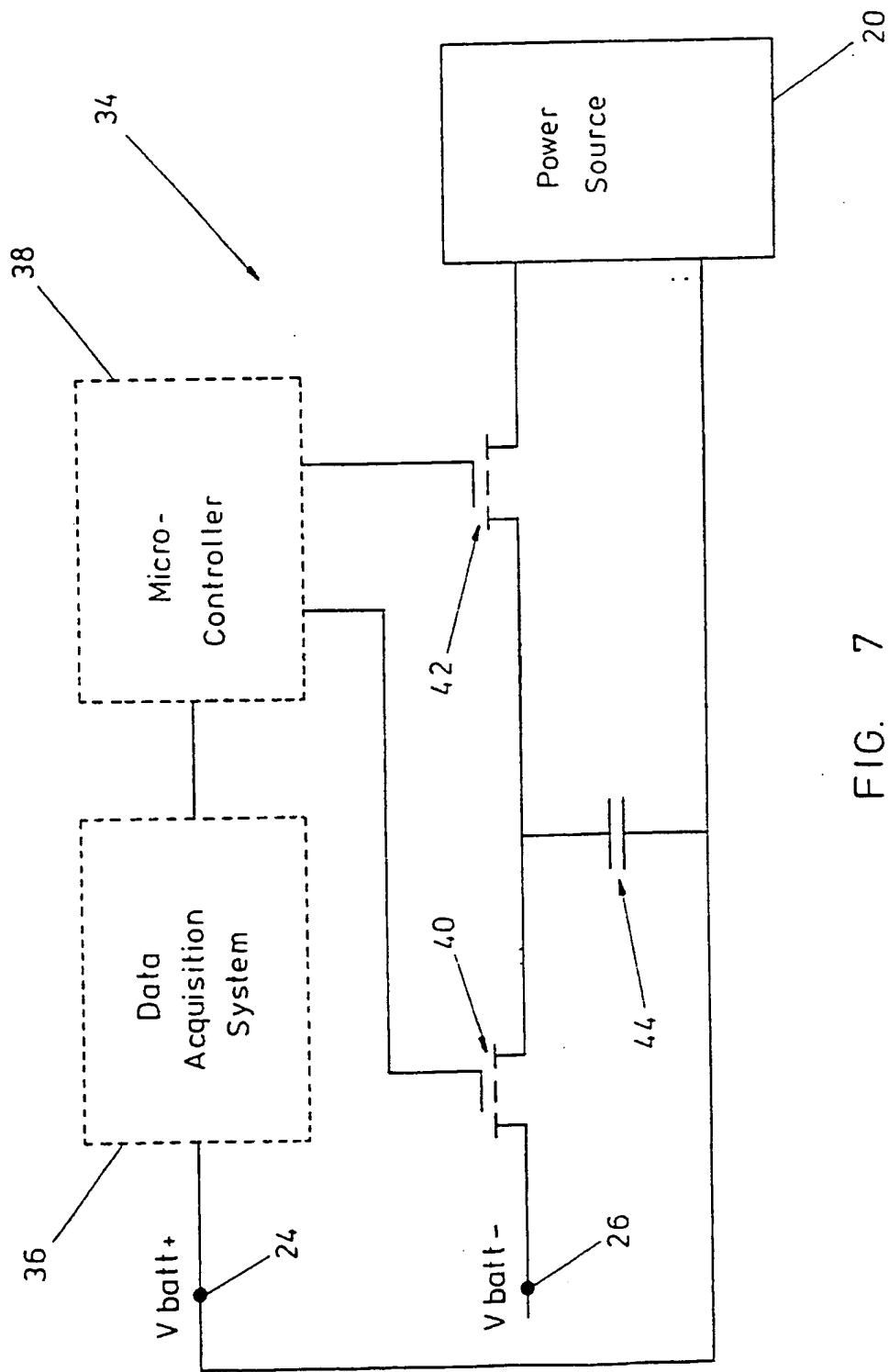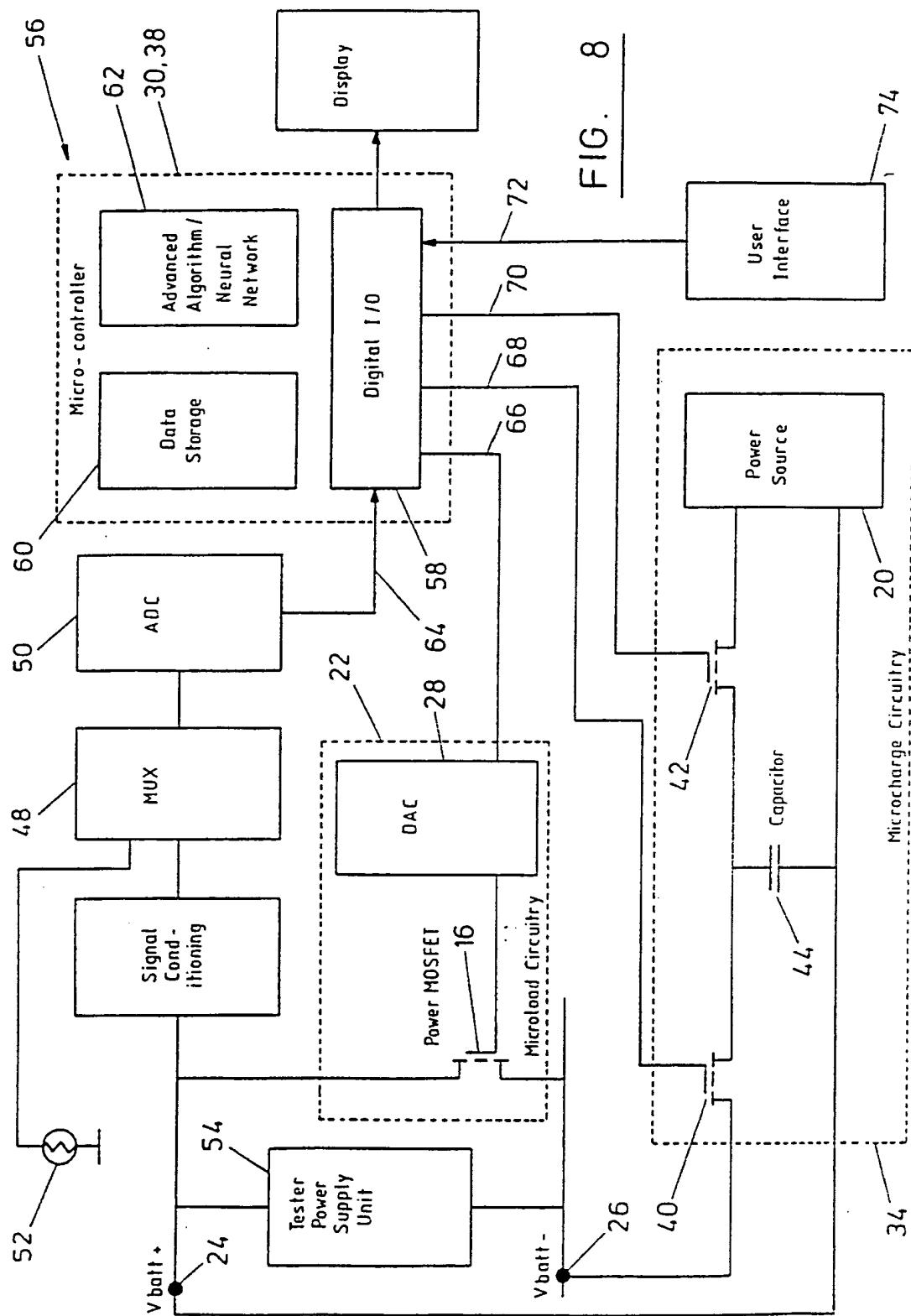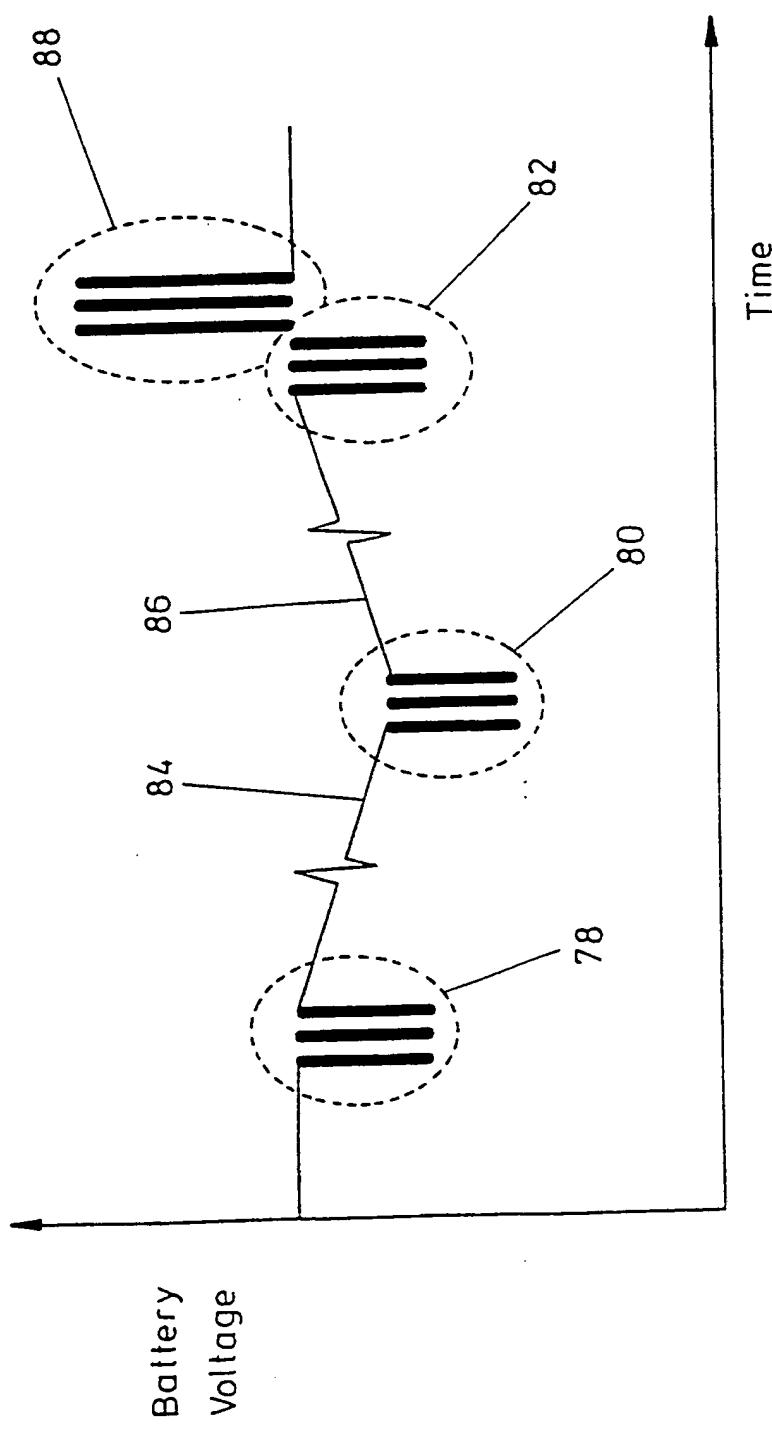
FIG. 9
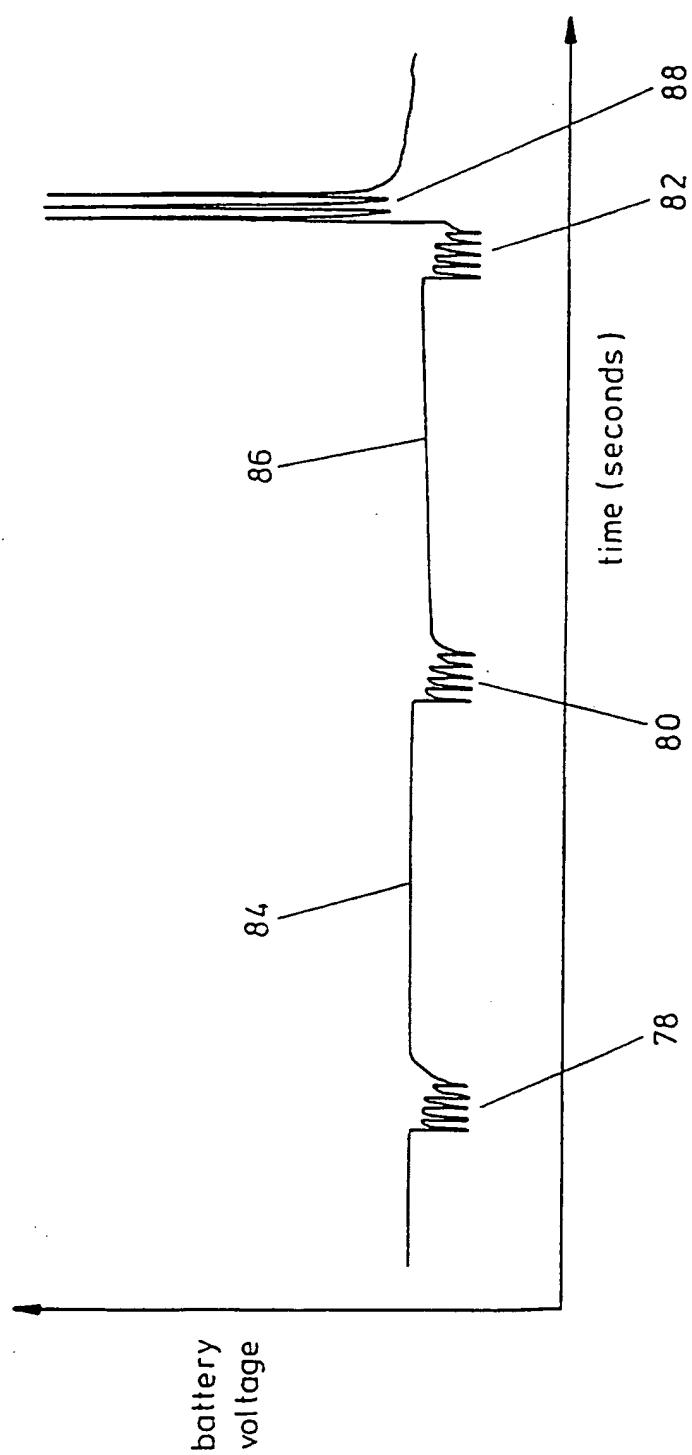
FIG. 10

FIG. 11
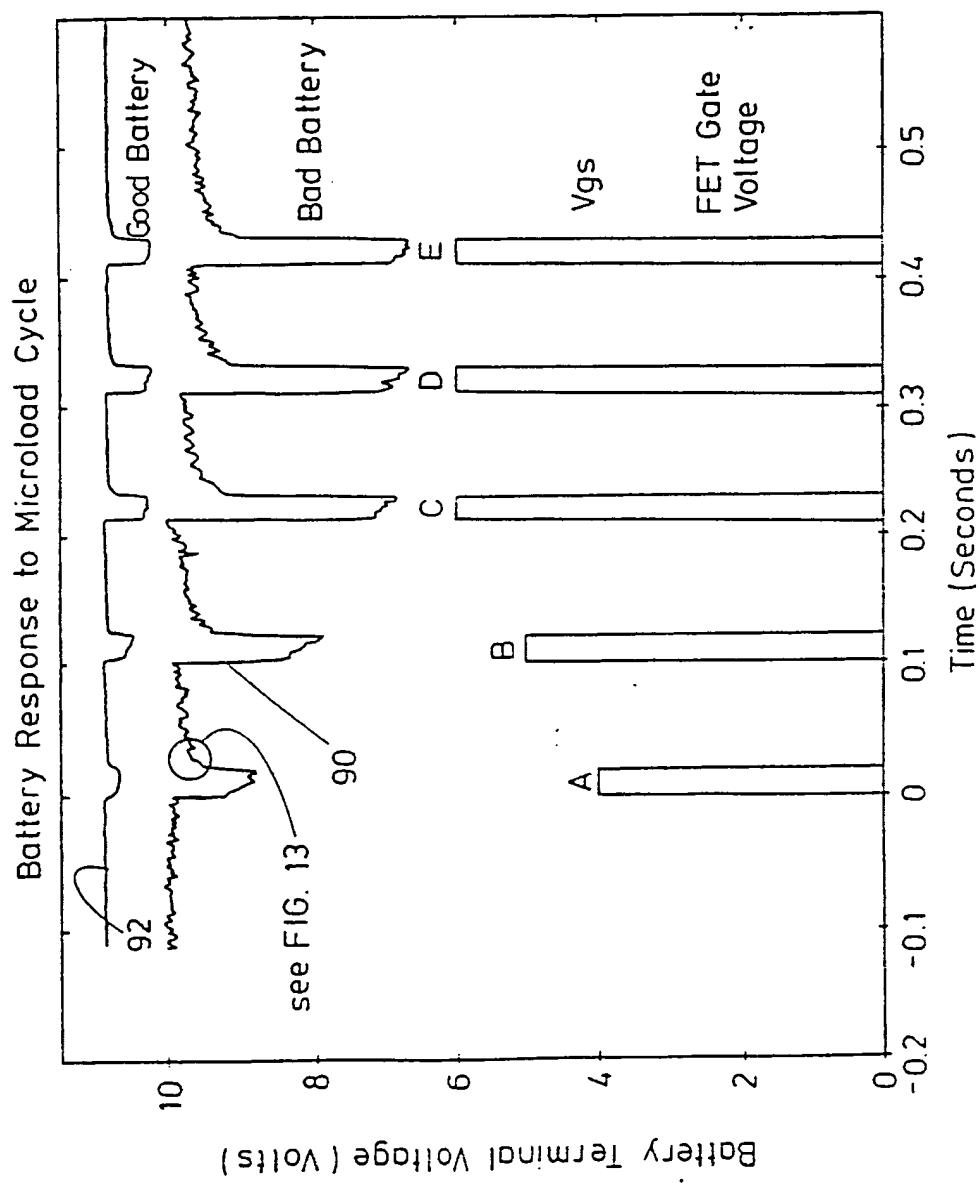
FIG. 12
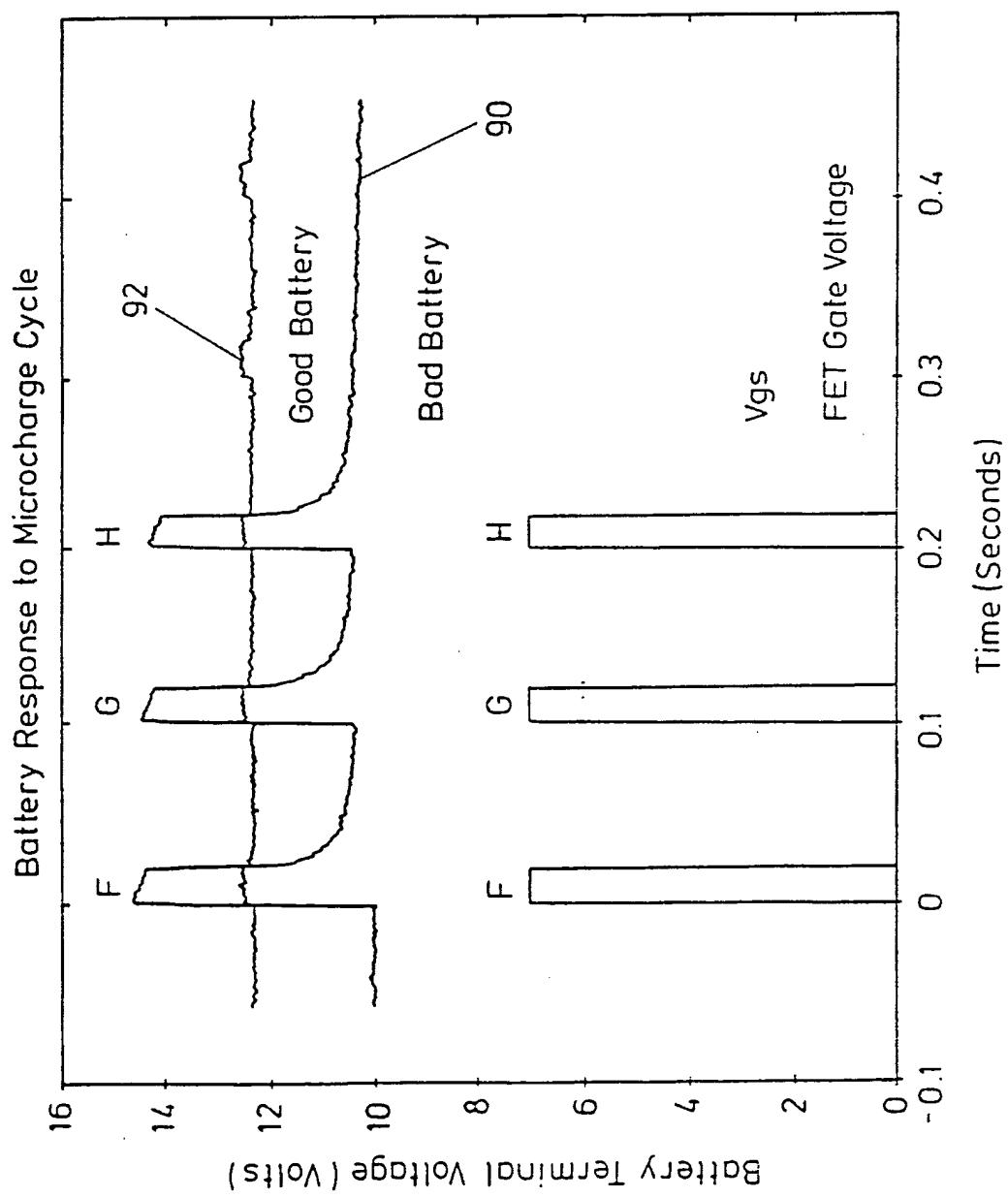
FIG. 13
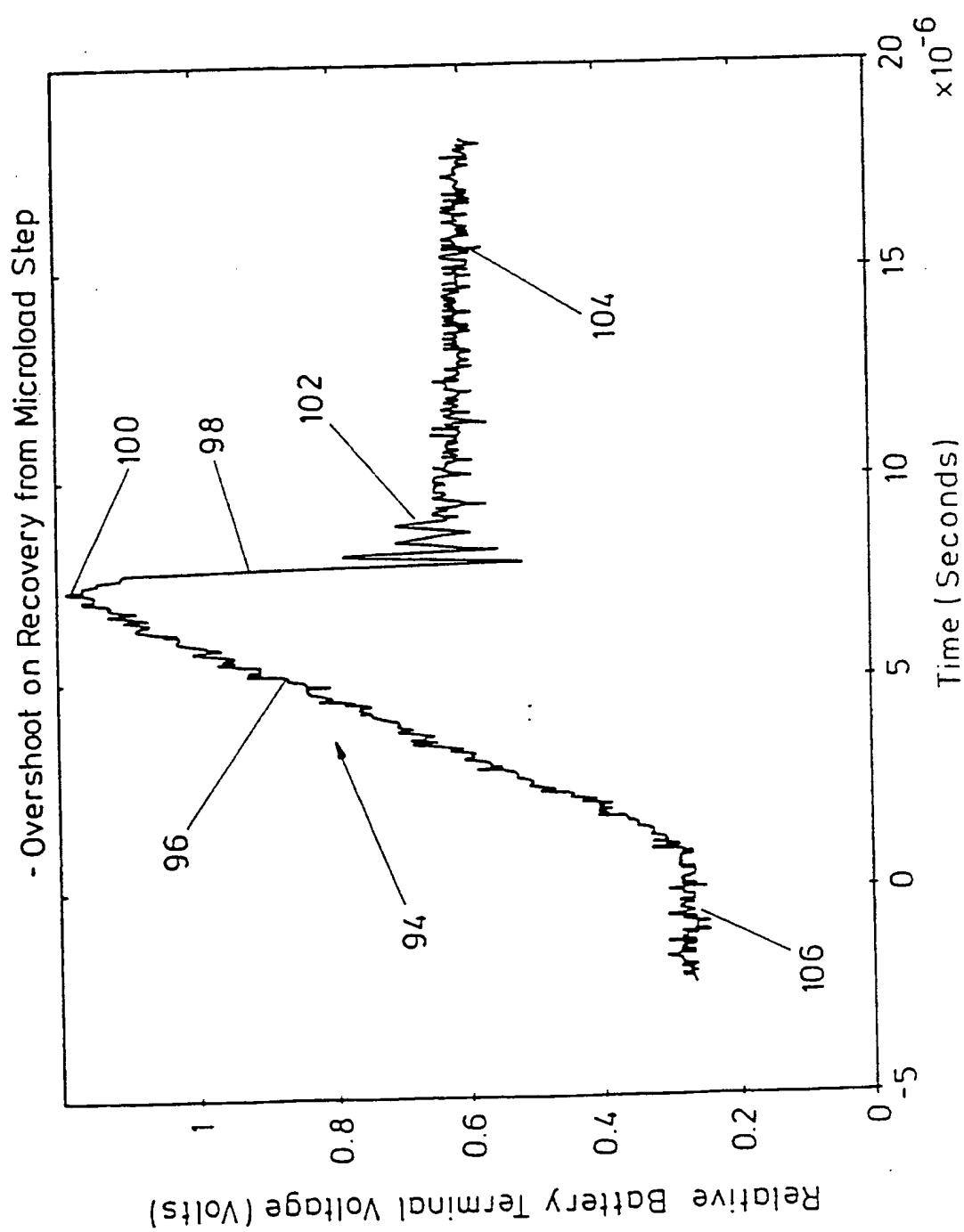
Worded Algorithm for Tester
Including Hardware Considerations

Check tester power supply:-
    if tester power supply <8·3V
        then flash 'on' LED
        and end
    if tester power supply >8·3V
        then test

Check battery terminal voltage:-
    light 'busy' LED
    if battery terminal voltage >12·4V
        then conduct microload test
            if drop under microload is between 0 and 2V
                then light 'good' LED
            if drop under microload is between 2 and 6V
                then light 'charge and retest' LED
            if drop under microload is >6V
                then light 'bad' LED
    if battery terminal voltage is between 11.8 and 12.4V
        then conduct microload test
            if drop under microload is between 0 and 2V
                then light 'good' LED
            if drop under microload is between 2 and 9V
                then light 'charge and retest' LED
            if drop under microload is >9V
                then light 'bad' LED
    if battery terminal voltage is between 10.5 and 11.8V
        then conduct microload test
            if drop under microload is between 0 and 2V
                then light 'charge and retest' LED
            if drop under microload is >2V
                then light 'bad' LED
    if battery terminal voltage is between 9.0 and 10.5V
        then conduct microload test
            if drop under microload is between 0 and 2.5V
                then light 'charge and retest' LED
            if drop under microload is >2.5V
                then light 'bad' LED
    if battery terminal voltage is between 0.1 and 9.0V
        then light 'bad' LED
        and end
    if battery terminal voltage is <0.1V
        then flash 'busy' LED
        and end
    terminate 'busy' LED
   and end

FIG. 14

FIG. 15

Bad

N

Drop
Under Load
$2 < d <= 9$

Y

Charge
and Retest

N

Initial
Battery V
$11 \cdot 8 < V < 12 \cdot 4$

N

Y

Drop
Under Load
$0 <= d <= 2$

N

Y

Good-
Recharge

Link 1

Bad

N

Drop
Under Load
$2 < d <= 6$

Y

Charge
and Retest

N

Initial
Battery V
$> = 12 \cdot 4$

N

Y

Drop
Under Load
$0 <= d <= 2$

N

Y

Good
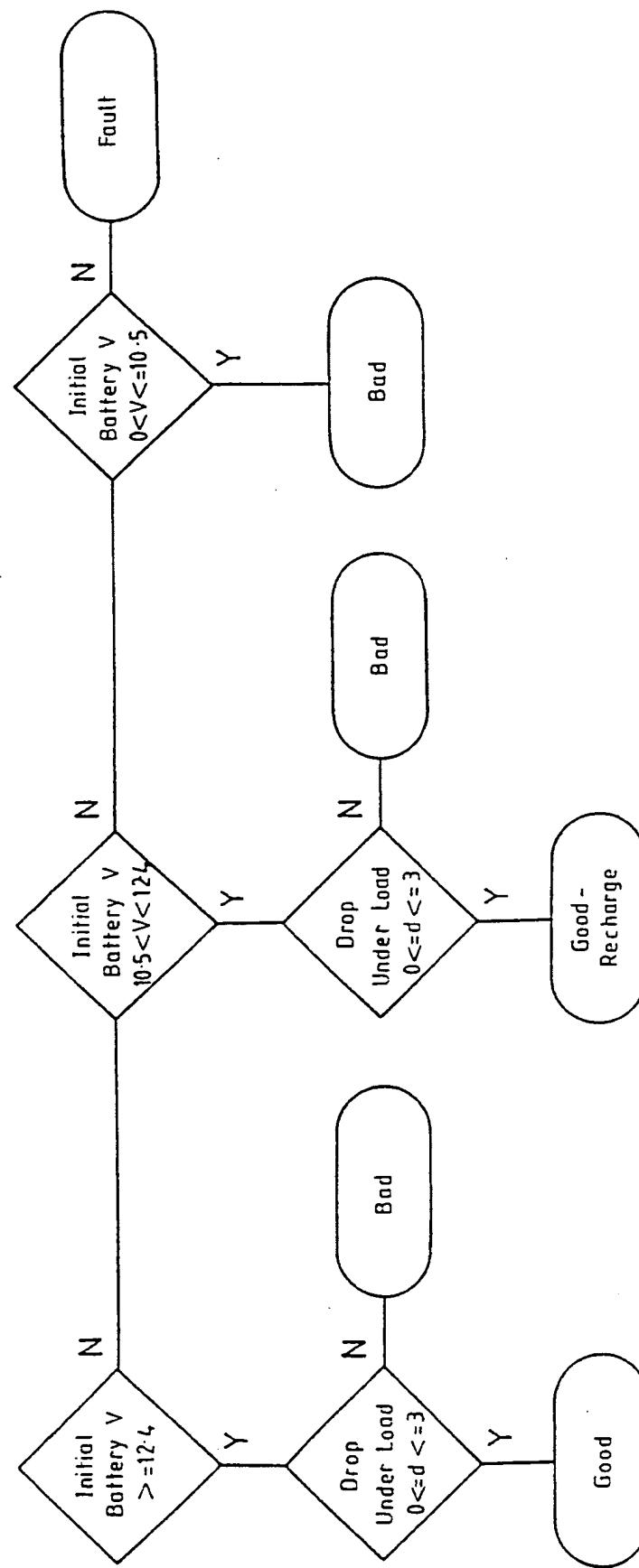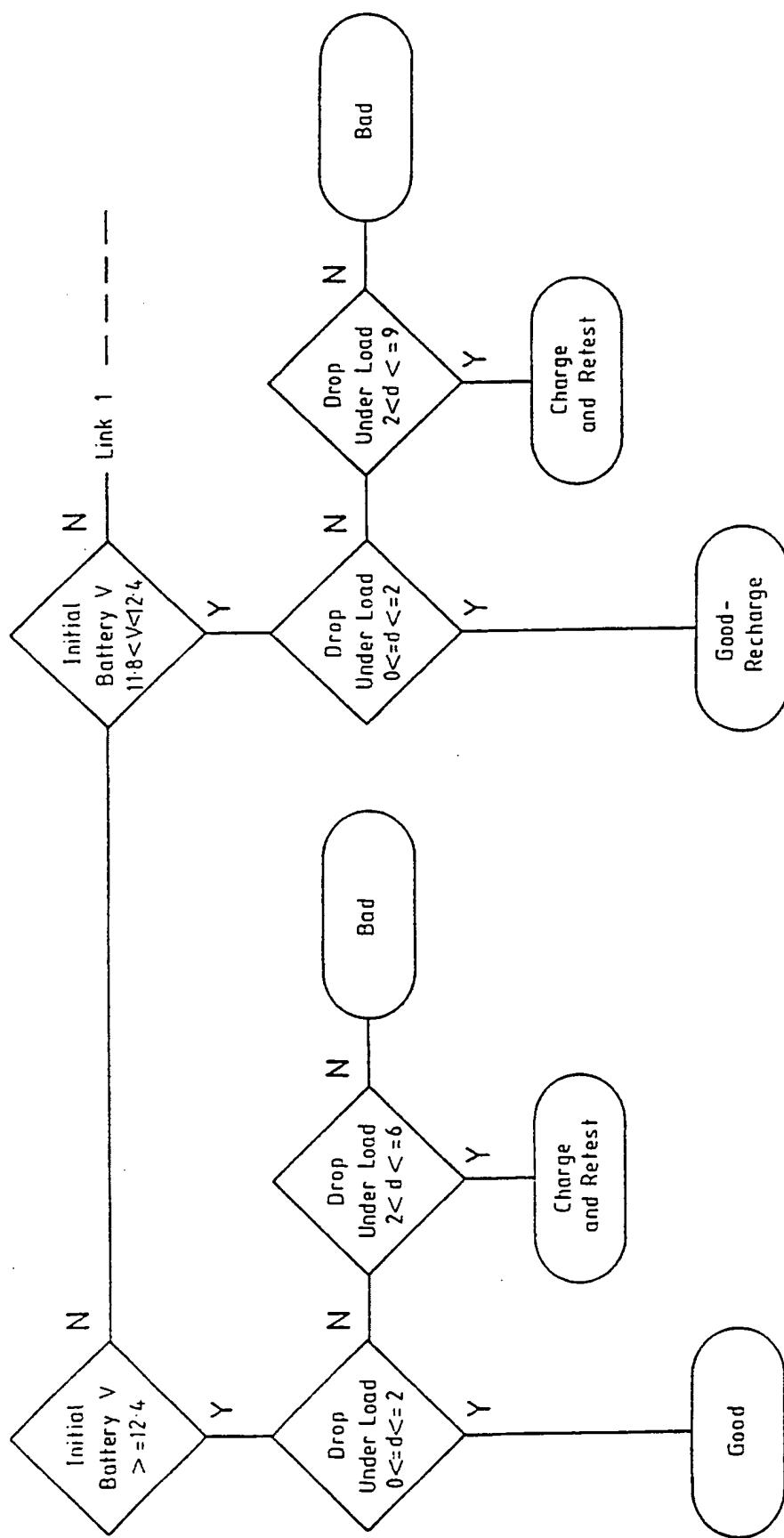
FIG. 16A

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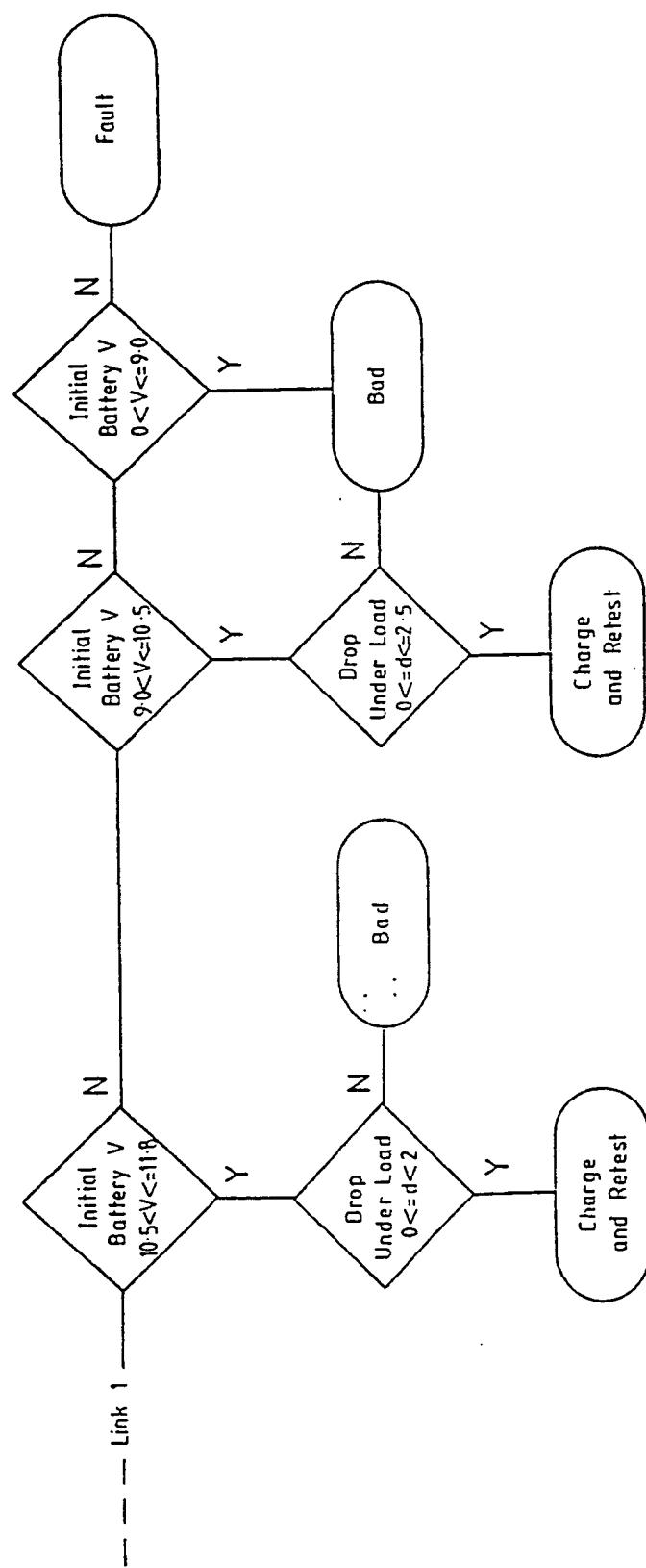
FIG. 16B

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6   G01R31/36   H02J3/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6   G01R   H02J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 772 056 A (PHILIPS ELECTRONIQUE LAB ;PHILIPS ELECTRONICS NV (NL)) 7 May 1997 see claims 1,3	1-4,7,8, 13,14, 22,23, 31,32,34
X	US 5 596 260 A (MORAVEC HANS P ET AL) 21 January 1997 see claims 1,9	1-4,7
A	EP 0 637 754 A (SEIKO EPSON CORP) 8 February 1995 see claims 1,2	1,7

☐ Further documents are listed in the continuation of box C.　　　　☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 October 1998	09/10/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Six, G

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
EP 0772056	A	07-05-1997	FR	2740555 A	30-04-1997
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			WO	9531734 A	23-11-1995
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